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**SSH-2 Measurements of Cirrus at 18-28 μ m
from the King Air During FIRE II**

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1. INTRODUCTION

In November of 1991, the First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment (FIRE) Phase II cirrus study took place at Coffeyville Kansas. The field experiment incorporated instrumentation from surface, aircraft and satellite to attempt to define the optical, radiative and microphysical characteristics of these high altitude, predominantly ice clouds¹. The NCAR King Air research aircraft was outfitted with a variety of radiative and microphysical instrumentation for the FIRE II project. Included for this project was the SSH-2, a 16-channel passive radiometer. The SSH-2 was originally designed as a space-qualified infrared (IR) temperature and water vapor sounder for deployment onboard the Defense Meteorological Satellite Program (DMSP) series of environmental satellites. For this experiment, only those channels associated with the water vapor profiling function have been examined although downwelling radiance measurements were taken at all channels during the project. With supporting information from the aircraft telemetry observations it may be possible to relate these SSH-2 measurements to cloud radiative and microphysical properties. The following sections will describe the spectral characteristics of the instrument, the calibration scheme used to convert the raw measured counts into calibrated radiances and the case studies that will be covered in this paper. This will be followed by a discussion of the results of this preliminary investigation and a description of future work to be done.

2. INSTRUMENT DESCRIPTION

In the early 1970s, DMSP developed an IR sensor, the SSH, to obtain atmospheric temperature and humidity information from space-based platforms. In 1978, a decision was made to break with the traditional IR sounding sensors and develop a suite of microwave sensors to perform the temperature and water vapor sounding tasks. With this change in direction, the lone remaining IR sounder (SSH-2 Serial #8) was placed in storage for a period of 12 years. In late 1990, the instrument was obtained by the Phillips Laboratory, Geophysics Directorate to be used for terrestrial applications, specifically, the FIRE II field project.

The SSH-2 employs 16 channels located: near the 15 μ m CO₂ band, in the water vapor rotational band from 18 - 28 μ m, in the IR window (11 - 13 μ m) and at 3.7 μ m (Table 1.). Prior to installation of the SSH-2 into the King Air some internal modifications were performed in the laboratory. Since the instrument is self calibrating and the cold space calibration is no longer feasible, a cold calibration source was added to the instrument. A portable personal computer was attached to serve as the controller and data acquisition system using software written to access and decode the data stream and to control the scanning mechanism of the SSH-2. With these modifications in place, the SSH-2 was pressure mounted directly to an upward-looking open viewport to avoid the problem of limitations in the spectral bandpass of the aircraft windows.

Measurements at each channel were made every second for a period of 128 seconds followed by a 32 second calibration sequence. Both internal warm and cold calibration sources are sampled during each calibration period for all 16 channels but the physical source temperatures are only measured every 15 minutes of operation. Aircraft telemetry data (ambient temperature, pressure, aircraft pitch, roll, etc.) was

accumulated and stored separately by NCAR RAF. The King Air also carried particle characterization instrumentation which provide *in-situ* measurements of cloud particle content, size, concentration and phase.

Calibration measurements were performed at intervals of approximately 2-3 minutes. The SSH-2 was designed to respond linearly to changes in the amount of radiation entering the system, therefore the conversion from instrument counts to radiant energy involves a simple linear regression of the instrument output to the energy input at each filter.

3. CASE STUDIES

During the intense observation period of 25-26 November 1991, the King Air flew three missions with two on 26 November. Flight 1 on the 26th was a clear air flight with little or no cloud cover over the central instrument site. The King Air took off at 1053 UTC from the Coffeyville, KS airport and gradually ascended to 8.5 km maintaining a relative ground position over the site (upward spiral). At 1143 UTC the King Air reached altitude and begun its descent back to Coffeyville again in a spiral over the site landing at 1237 UTC. The flight provided a unique opportunity to obtain background water vapor signals from the SSH-2 without contamination from cloud liquid water and ice particles. The lack of cloud moisture was confirmed by coincident radiosonde, raman lidar measurements and onboard particle measuring equipment during the course of the flight.

A plot of the calibrated downwelling radiance (or for this graph T_b) versus aircraft altitude for all 7 channels is shown in Figure 1a. The graph of each channel is denoted by its center wavenumber. As expected all seven channels display decreasing T_b with increasing altitude. Channel 16 (533 cm^{-1}) has the

Table 1. SSH-2 instrument channels, spectral bands and relative transmission characteristics.
(CW = Center Wavenumber/Wavelength, FWHH = Full Width Half Height)

Channels	CW (cm^{-1})	FWHH (cm^{-1})	CW (μm)	FWHH (μm)	Spectral Bands	Relative Characteristics
1	668.3	2.3	14.963	0.051	CO ₂ Band Shoulder Window	Opaque Transparent
2	676.6	9.6	14.78	0.21		
3	695.5	10.1	14.378	0.209		
4	707.4	9.1	14.136	0.182		
5	731.2	9.7	13.676	0.181		
6	746.4	11.3	13.398	0.203		
7	796.5	10.9	12.555	0.172		
8	898.4	11.7	11.131	0.145		
9	2657.7	274.6	3.763	0.39	Window	
10	355.5	14	28.129	1.108	Water Vapor Rotational Band	Opaque Less Opaque
11	396.7	10	25.208	0.636		
12	409.3	12.4	24.432	0.74		
13	419.8	19.9	23.821	1.13		
14	440.6	18.3	22.696	0.943		
15	496.6	14.2	20.137	0.576		
16	533.2	14.4	18.755	0.507		

least decrease in T_b with height and Channel 10 (356 cm^{-1}) the largest change. Channel 10 is in a spectral region of high water vapor absorption and therefore its sampling volume would be limited to a region close to the aircraft. The two channels (497 and 533 cm^{-1}) have the smallest range of the SSH-2 channels due to their location in less absorbing regions of the water vapor rotational band. All channels display a quasi-constant change in T_b with altitude except for a small anomaly at approximately 4.3 km presumably due to the passage of the King Air under a thin contrail. Due to the dry atmospheric conditions that existed on the morning of 26 November 1991 the curves in Figure 2 should represent the minimum radiance or coldest T_b that each channel should measure at the respective altitude.

The King Air made its second flight of the day departing at 1812 and landing at 2128 UTC. During the hours between the end of the first flight and beginning of the second, cirrus began to form over the area. As the system approached, the cirrus shield grew from relatively thin scattered cirrus to broken and then overcast cirrostratus partially obscured in the later afternoon by a mid-level cloud deck. The King Air initially climbed to 8.5 km passing through the base of the cirrus layer at approximately 6 km. At 1951 the King Air began a descent to 6.2 km through the cirrus deck using a step-down racetrack pattern with 0.3 km increments. Upon reaching 6.2 km the King Air flew a spiral over the central site up to 8 km where at approximately 2107 UTC it began its descent to the landing at 2128 UTC. Throughout the flight the King Air was either inside the cirrus deck or just below; the King Air did not have a flight ceiling high enough to reach the top of the cirrus layer.

Figure 1b is a graph of Channel 13 (420 cm^{-1}) versus time (seconds UTC) for Flight 2. Compared to the earlier flight there is considerably more variability to the measurements due to the inhomogeneities of the cirrus in the field of view. Since the SSH-2 channels respond to both the opacity of the atmosphere with respect to water vapor and to the microphysical characteristics of the particles in the channel sampling volume it is difficult to isolate a single effect or contribution from a single channel measurement. However, with knowledge of the clear sky atmospheric radiance it may be possible to isolate the contribution from the cirrus. Figure 2 is a plot of the channel 13 T_b for both flights on 26 November as a function of aircraft altitude. Clearly the T_b for the clear flight is less than that for the cirrus flight at all altitudes. The data for Flight 2 is shown as a range of values measured over the course of the flight as a function of altitude. The mean values for each altitude are shown by a connected line.

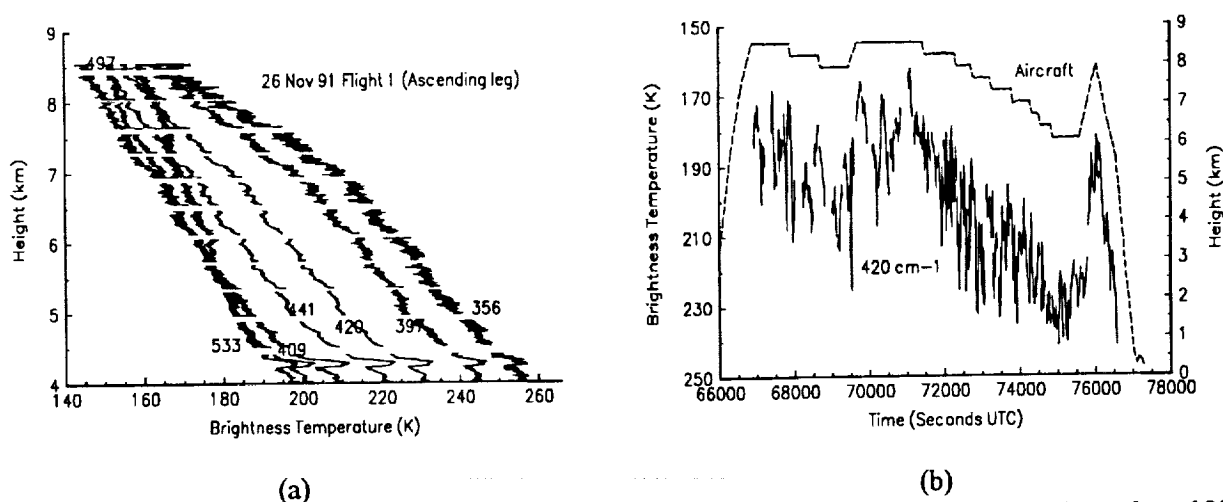


Figure 1. SSH-2 measured Brightness Temperatures for Flights 1 and 2 on 26 November 1991. Measurements are for a) the ascending leg of Flight 1 (versus aircraft altitude) for each channel and b) for Flight 2, Ch 13 (420 cm^{-1}) as a function of time with aircraft altitude also shown (not meant to match T_b scale).

4. DISCUSSION

It is advantageous to be able to separate the background radiance from the cloud radiance either through a theoretical model or as in this case with actual measurements. The timeliness of the two flights make this case study unique in that the assumption of unchanging background from flight to flight has more validity because of the short time separation. However, the question remains what can be recovered from the cloud radiances? Utilizing the PL MODTRAN atmospheric transmission model² the theoretical background channel radiances can be obtained as well as radiances for specific instances of cirrus occurrence. Two cirrus models are available to MODTRAN (thin and standard cirrus) which differ only in the size of particles used in the cirrus parameterization (4 and 64 μm , respectively). The model was run for both clear and cirrus (at 6-9 km) cases for an aircraft altitude of 6 km (Figure 3). The slopes of the three curves vary measurably from clear to cloudy scenes. In theory, since both cirrus cloud model runs used the same cloud physical and extinction characteristics, the difference in the curves should be due to the microphysical characteristics of the models (i.e., particle size). If this assumption is true then it may be possible to estimate the cirrus particle sizes from measurements by computing the slope of the channel T_b s or ratioing two channels that most closely characterize the spectral change in T_b .

5. ACKNOWLEDGMENTS

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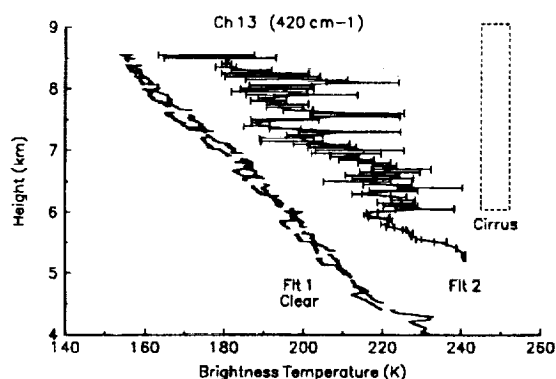


Figure 2. SSH-2 measurements for both clear and cirrus flights plotted together as a function of altitude for channel 13 (420 cm^{-1}).

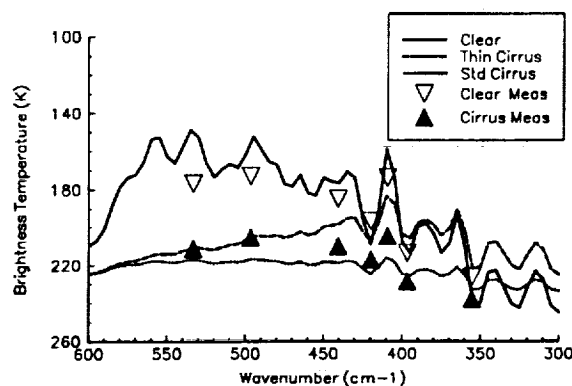


Figure 3. MODTRAN model estimations of the downwelling T_b at a 6 km altitude from a clear sky scene and from a 3 km cirrus layer at 6 km. The corresponding SSH-2 measurements are shown as triangles.